Uncertainty Quantification of GNSS RO Retrieval Products

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CLARREO SDT Meeting, Nov. 29–Dec. 1, Hampton, VA

Status of CLARREO-related tasks from past year

1. RO bending angle climatology for high altitude initialization (Nov 2015)
   - Algorithm being implemented/tested at JPL processing system
2. Trends and variability of the tropical width from RO, reanalysis, and climate models (May 2016)
   - Paper in preparation
   - To be presented at AMS Annual Meeting 2017
3. Collaboration with Knuteson & Feltz (UW) on understanding biases between IR & RO strato temperatures.
4. obs4MIPs monthly-averaged RO temperature and geopotential height datasets have been released.

Motivation: Establishing GNSS RO as reference observations

- Following the GRUAN (GCOS Reference Upper Air Network) paradigm:

✓ *Is traceable to an SI unit or an accepted standard*

✓ ***Provides a comprehensive uncertainty analysis***

✓ *Is documented in accessible literature*

✓ *Is validated (e.g. by intercomparison or redundant observations)*

✓ *Includes complete meta data description*

✓ ***Important to distinguish contributions from systematic error and random error***

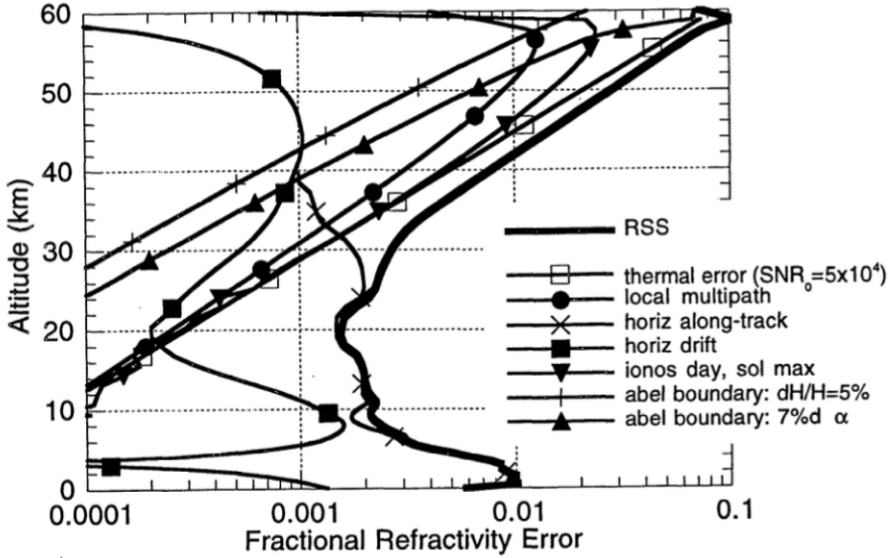
Existing works

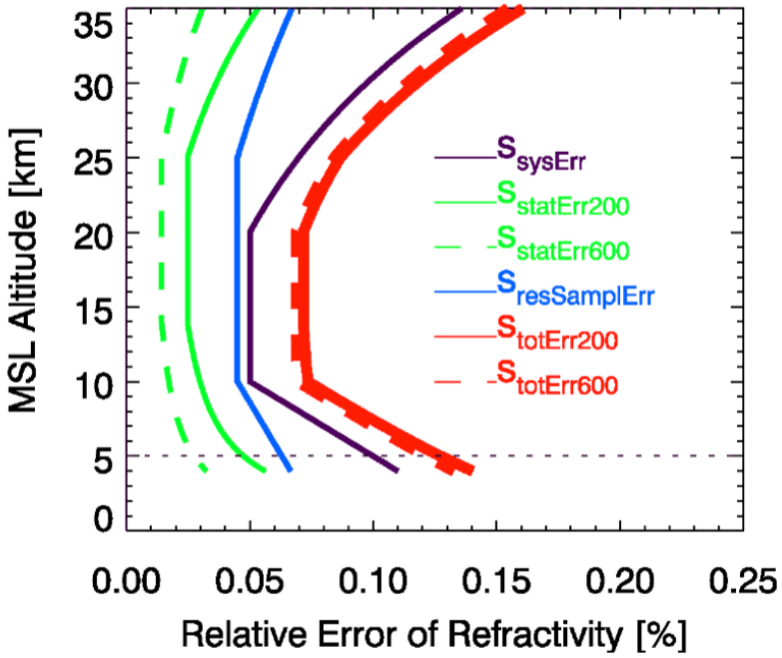
Kursinski et al., JGR, 1997

- Comprehensive analysis of multiple error sources.
- Did not separate systematic and random errors
- Derived under limited sets of parameters.

Scherlin-Pirscher et al., AMT, 2011

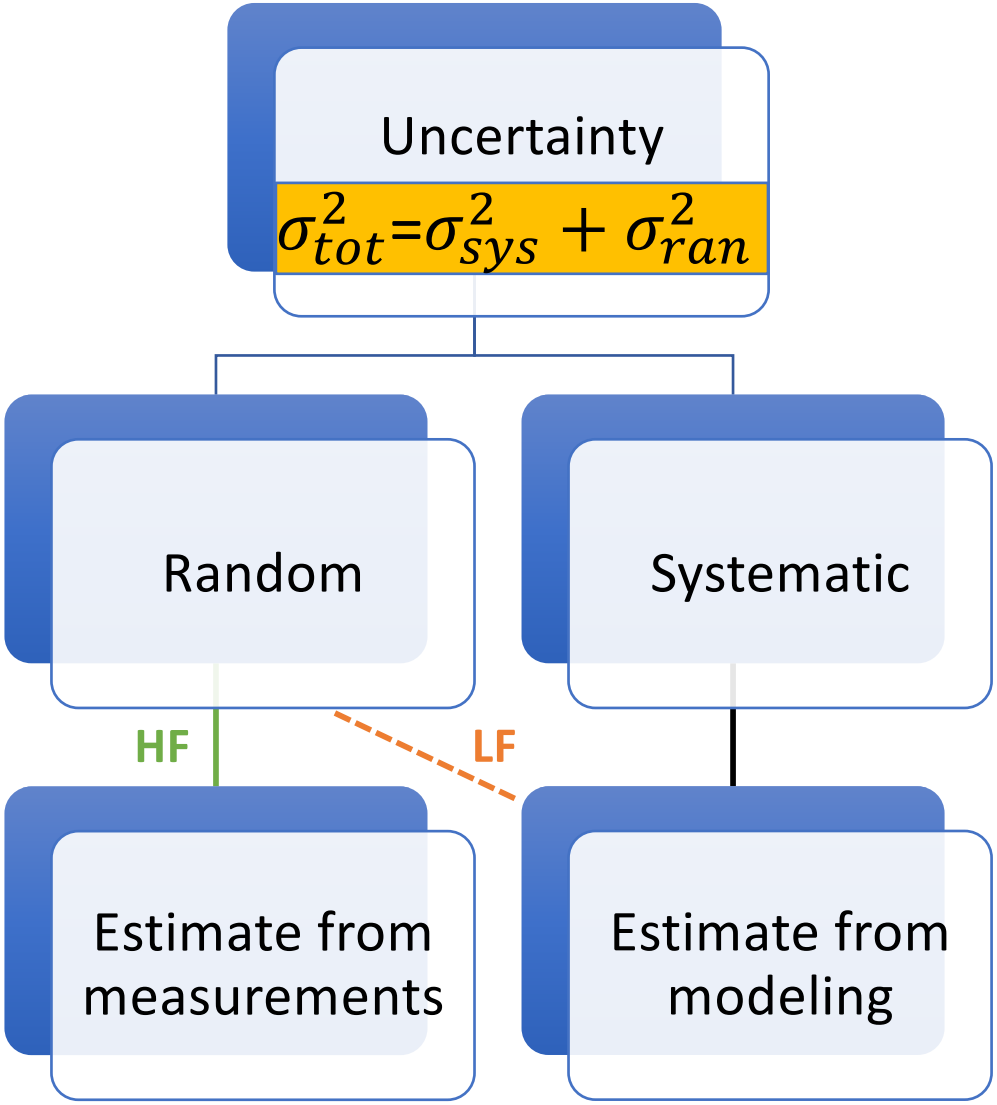
- Separated systematic and random errors (plus sampling error estimates).
- Considered only climatological averages.





Independent uncertainty estimates specific to a retrieval system are desirable.

Approach to per datum uncertainty estimation



Random = noise that averages down as ~ 1/sqrt(N), where N is the number of observations.

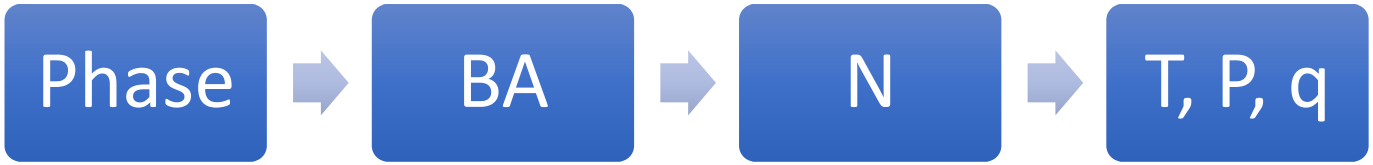
HF = High-frequency variations (uncorrelated noise from sample to sample)

LF = Low-frequency variations (from multipaths and possibly orbit/clock)

Estimating random errors

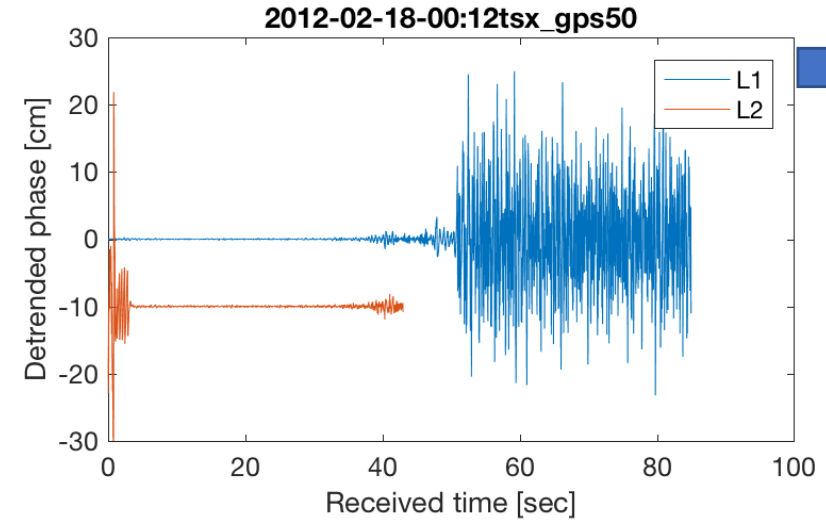
Estimate phase noise from the excess phase data:

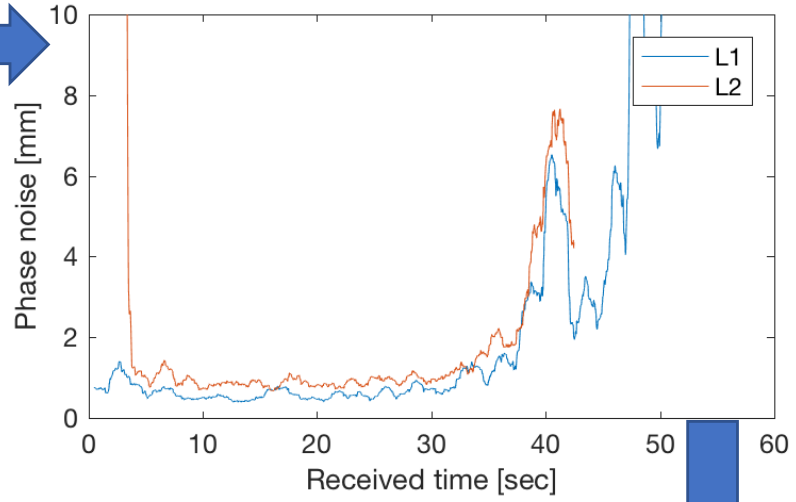
- Detrend phase and compute standard deviation over an interval containing many data points (e.g., 1 sec = 50 pts)
- Propagate phase uncertainty through retrieval chain (*analytically* or *Monte Carlo*)

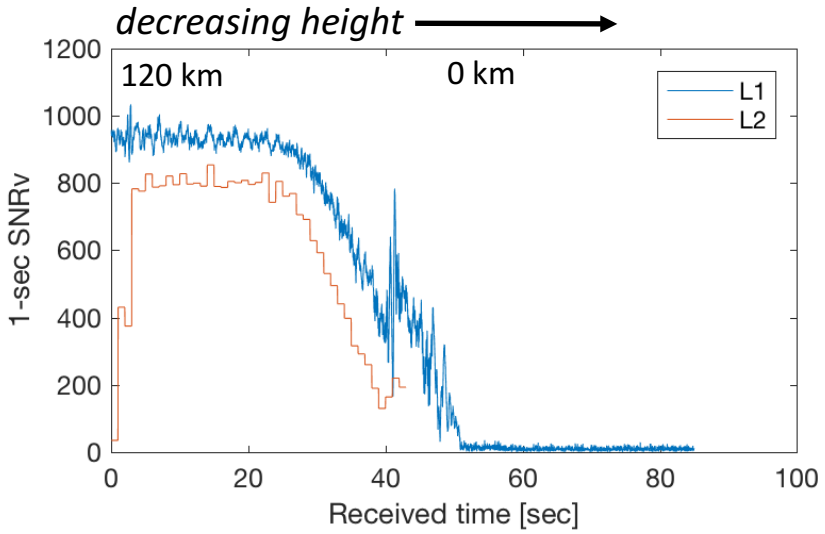


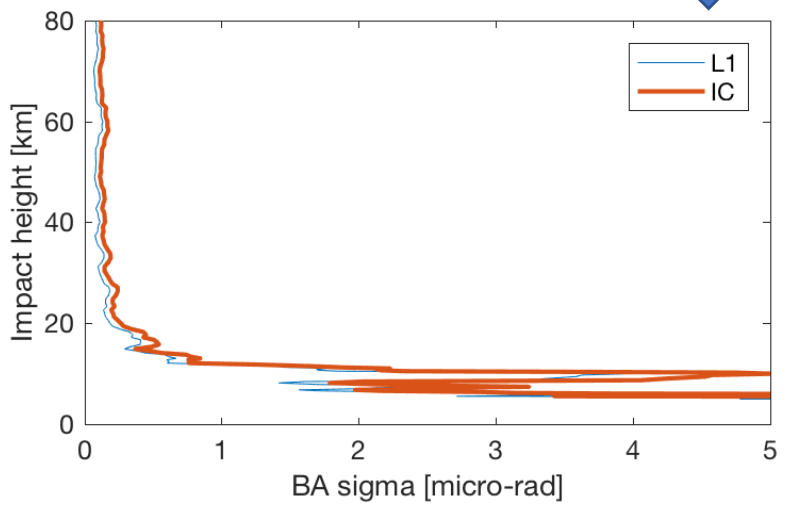
This method accounts only for "high-frequency" noise. It will not capture "low-frequency" phase variations such as those from local multipath.

Example 1: Phase to BA (Random)



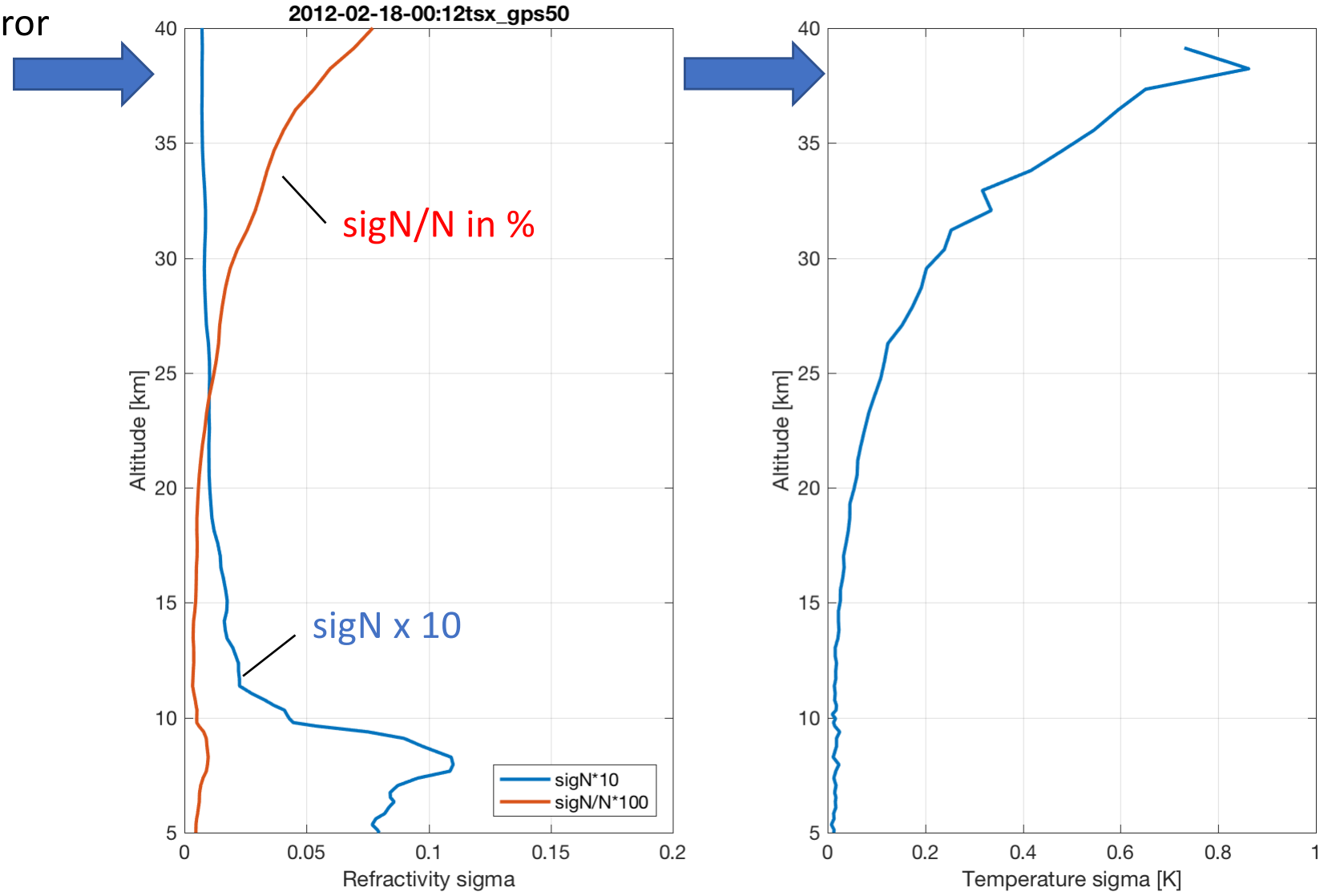




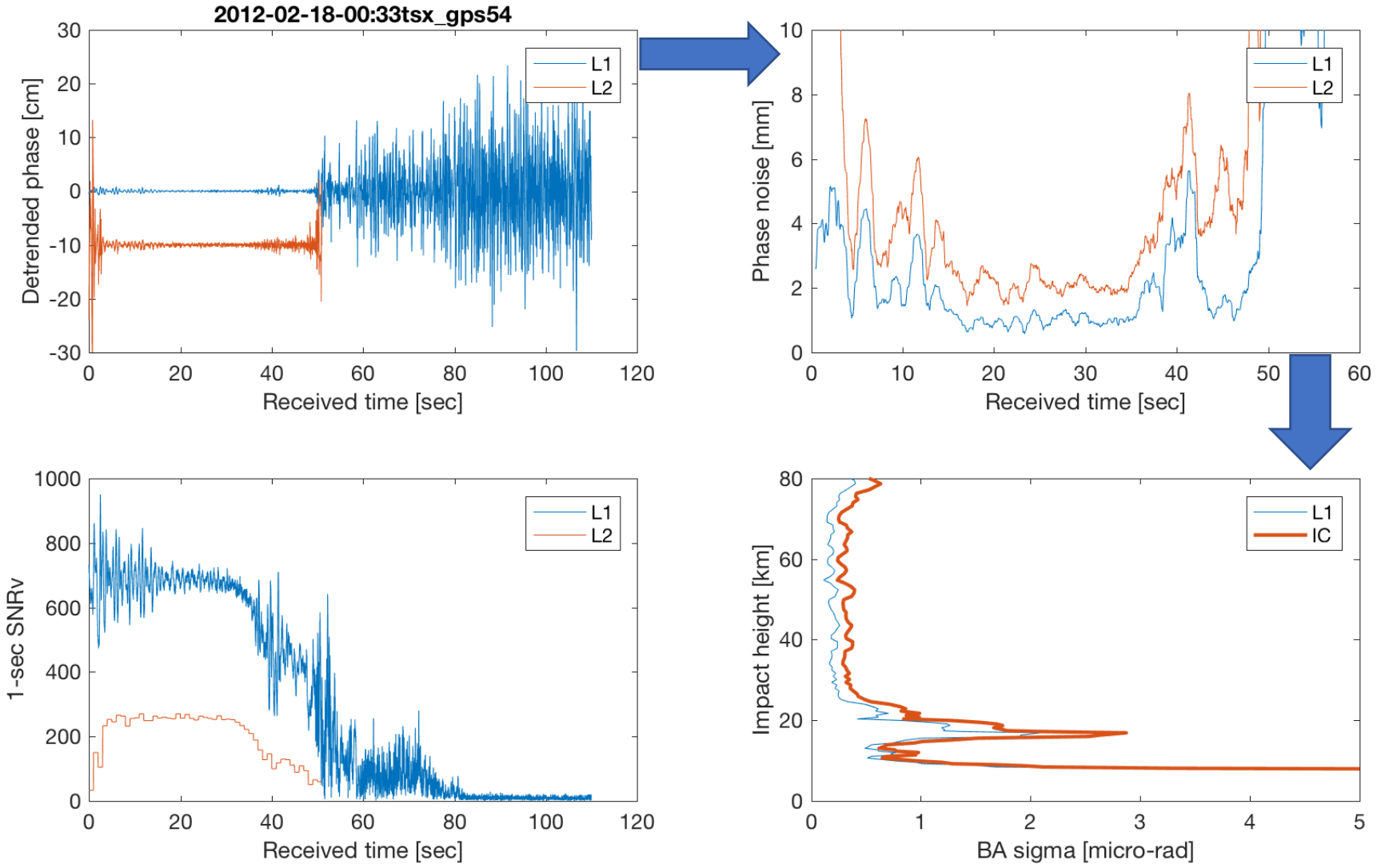


Example 1: BA to N to T (Random)

BA Error

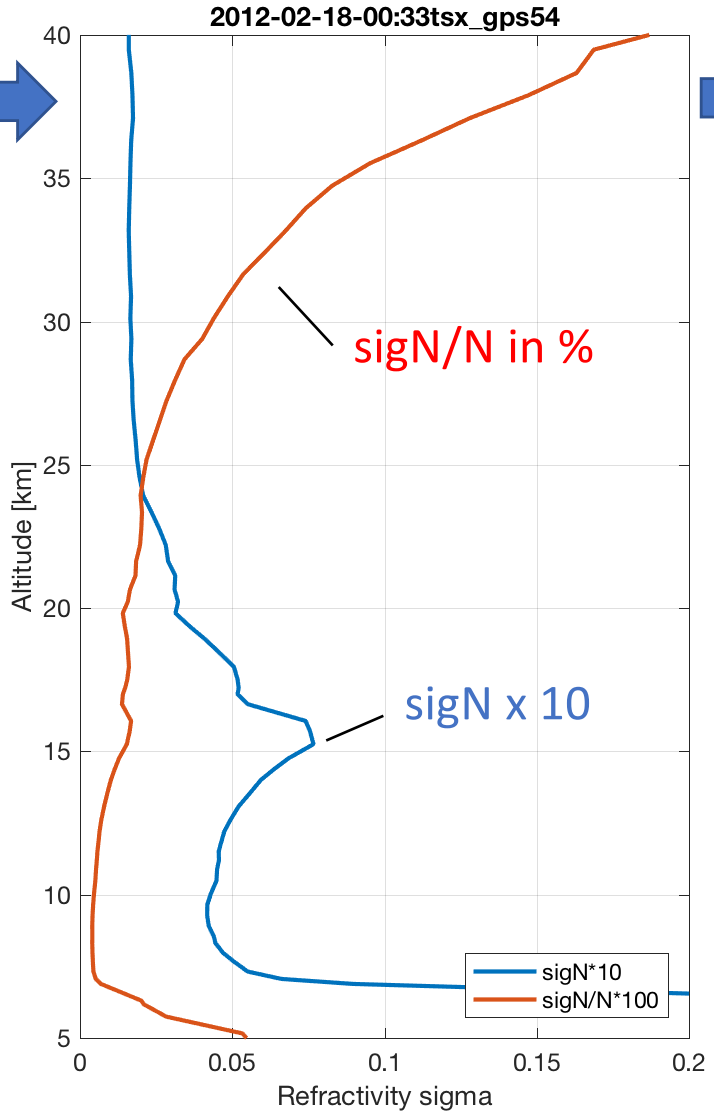


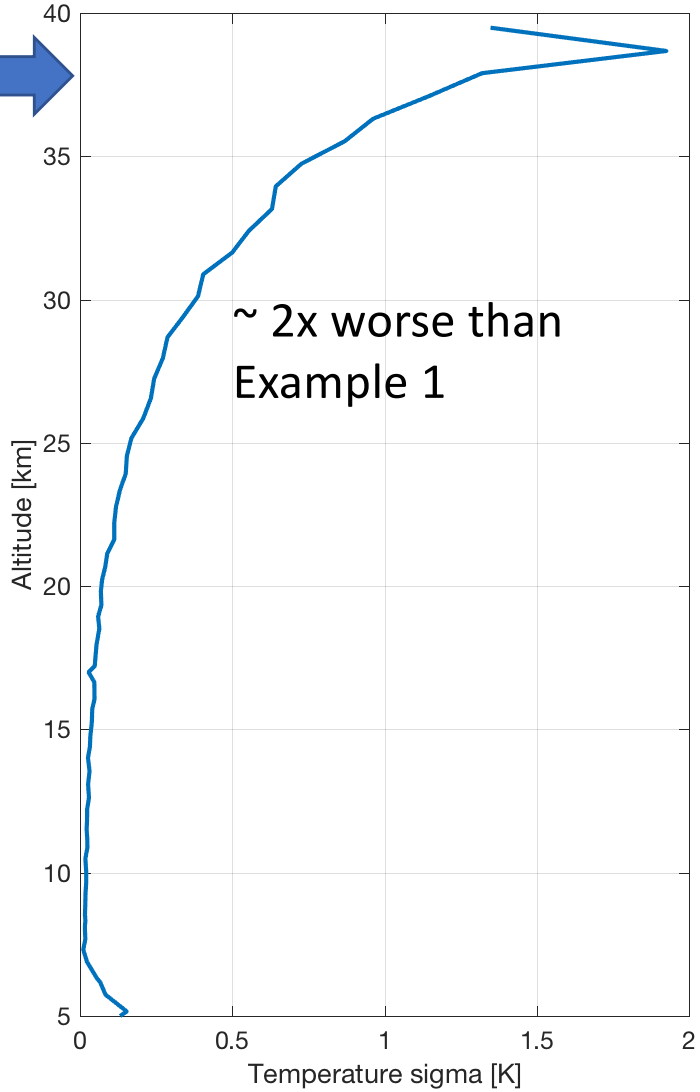
Example 2: Phase to BA (Random)



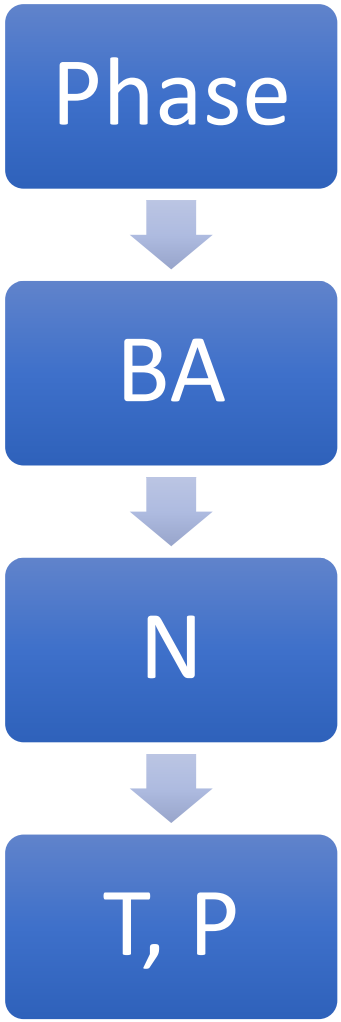
Example 2: BA to N to T (Random)

BA Error





Estimating systematic errors



Consider largest error sources for z > 10 km

Residual (large-scale) ionospheric error

Solar-max daytime condition ~ 0.1 micro-rad at all heights

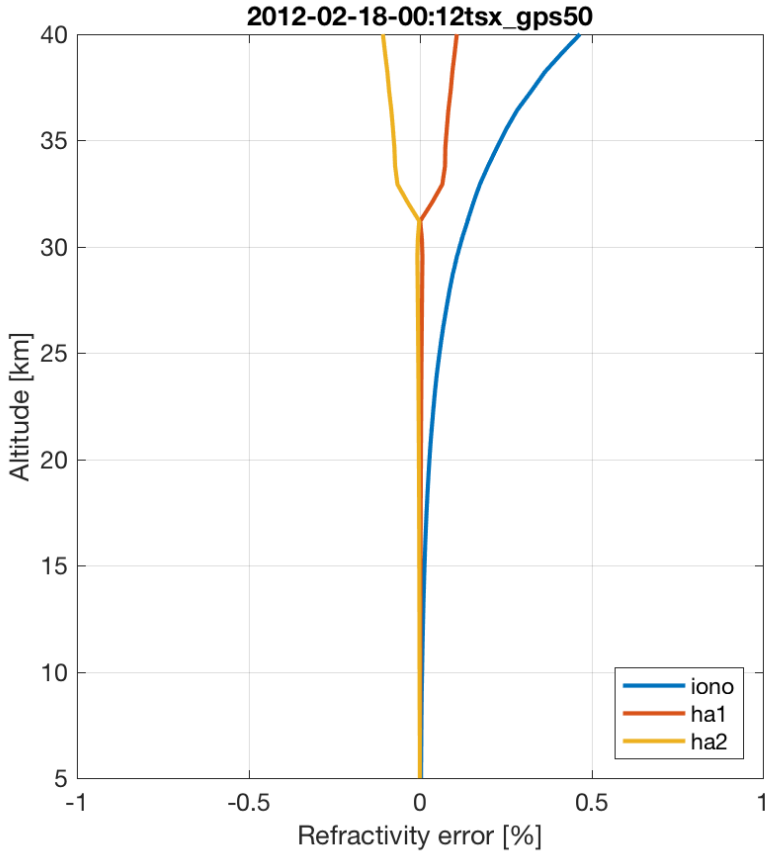
+ High-altitude Abel initialization

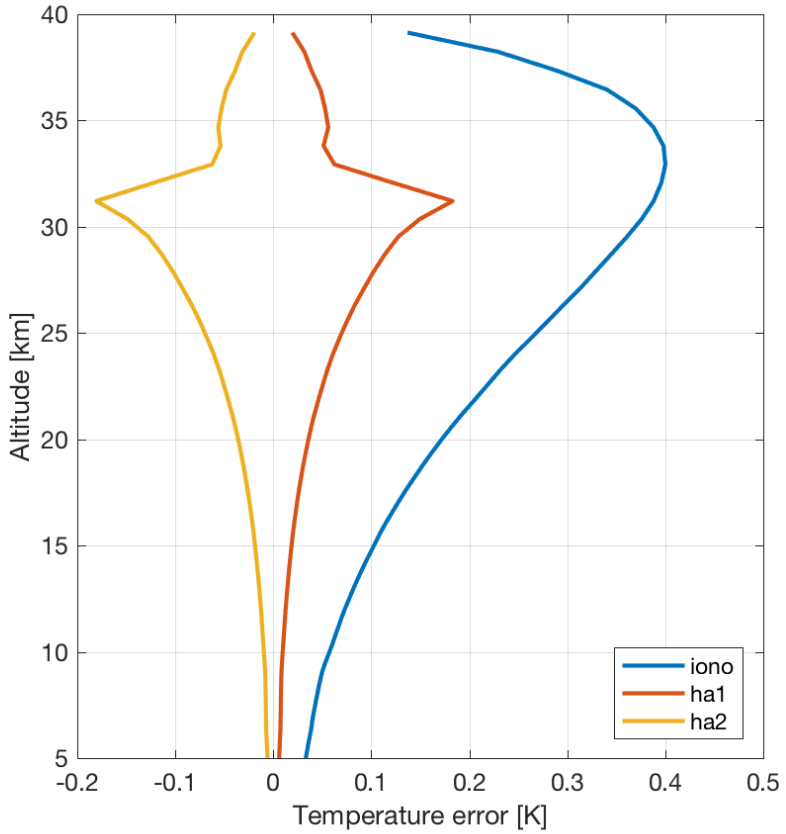
Estimated based on residuals of exponential fit as ± X% of best fit (typical values of X is 10)

+ Hydrostatic initialization of T

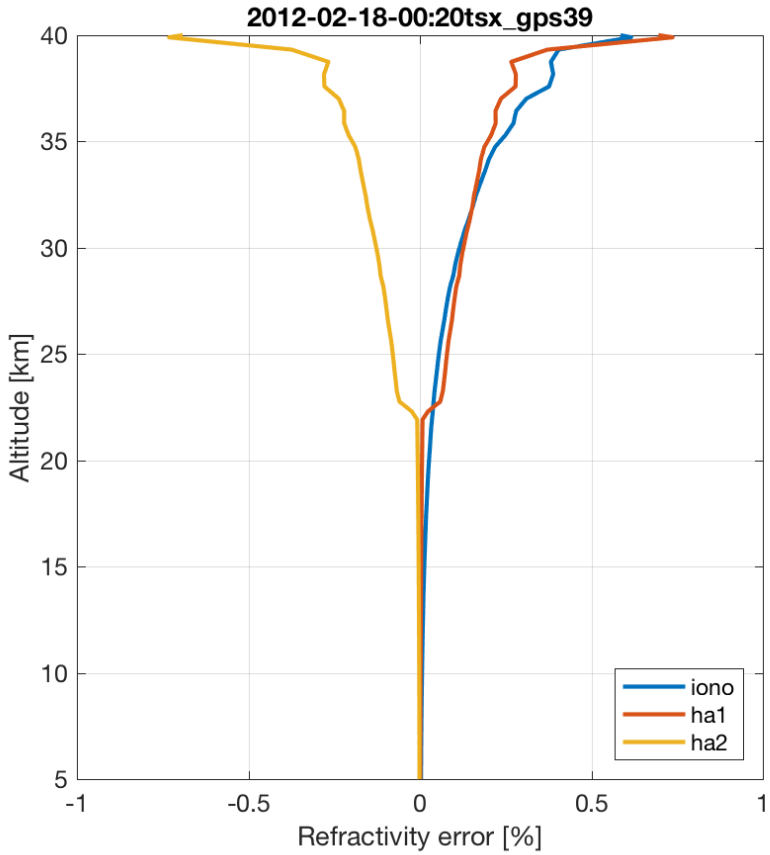
Estimated assuming ±5K uncertainty at 40 km initialization height

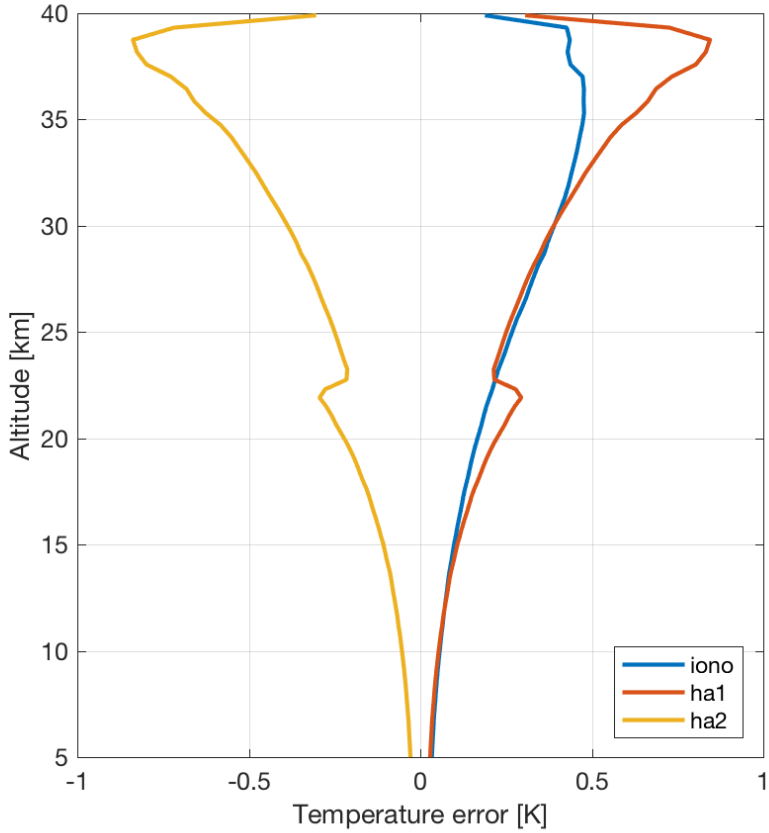
Example 1: Systematic, iono+ha



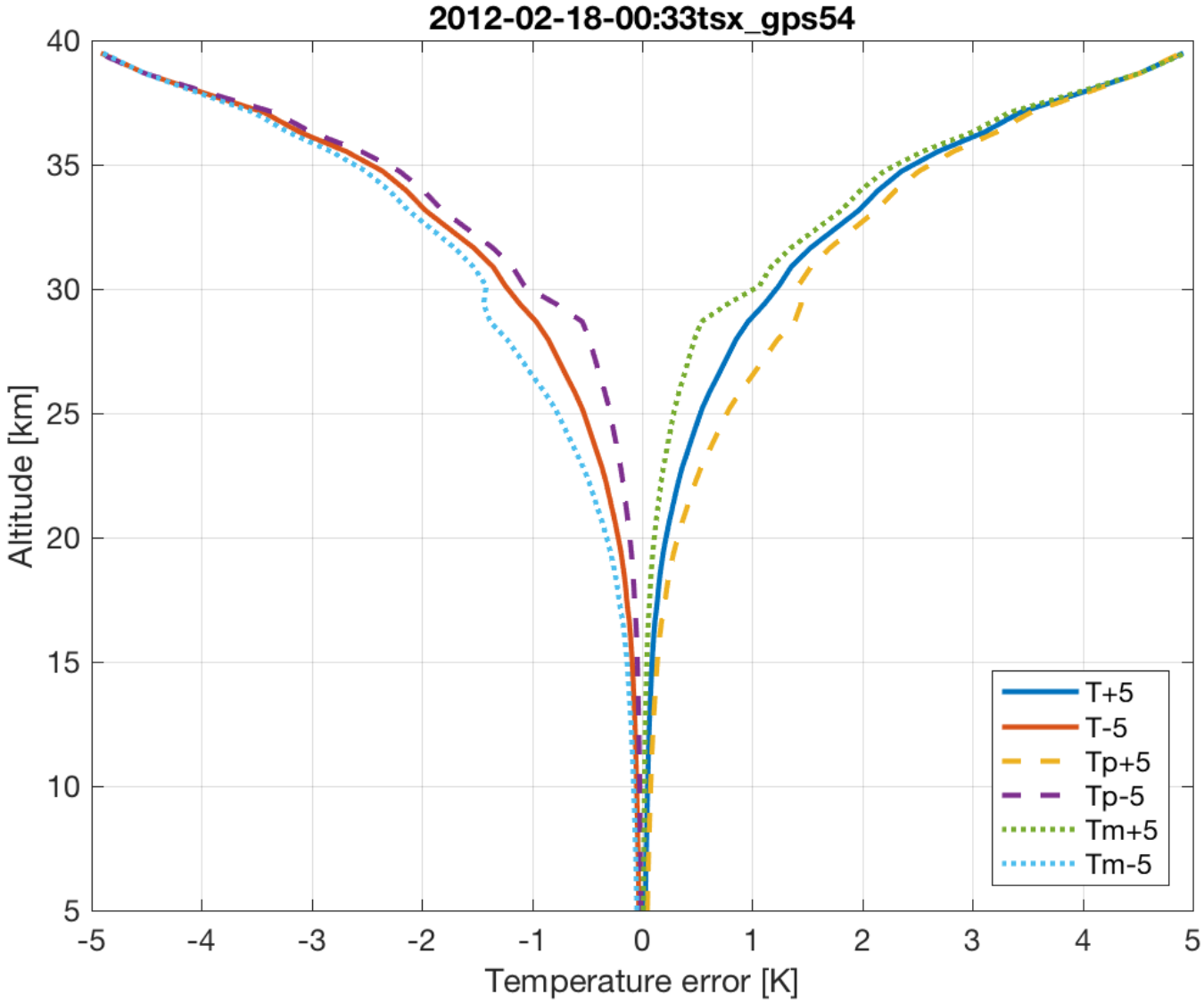


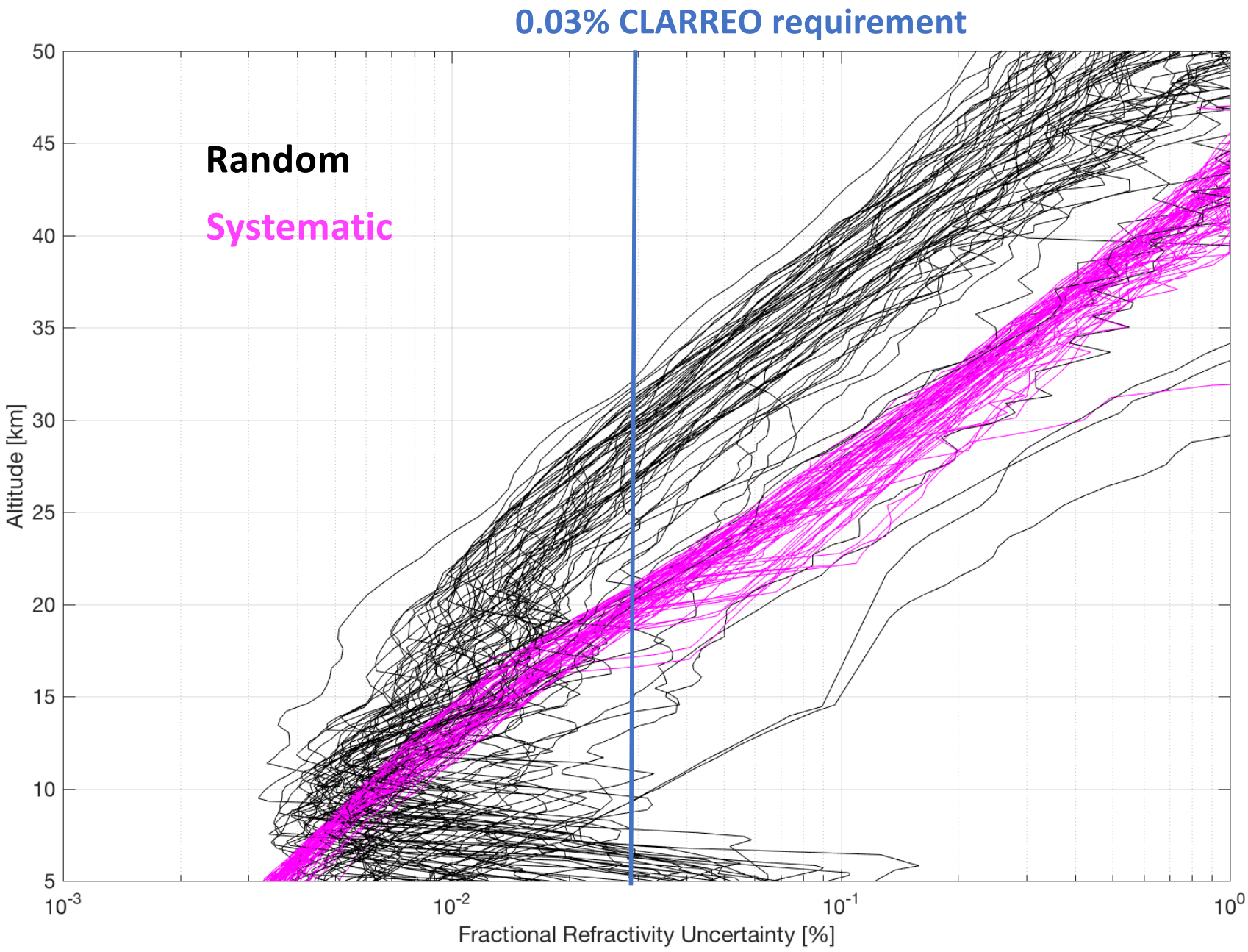
Example 2: Systematic, iono+ha





Example 2: Systematic, T init




0.03% CLARREO requirement
Random
Systematic
Altitude [km]
Fractional Refractivity Uncertainty [%]
50
45
40
35
30
25
20
15
10
5
10^{-3}
10^{-2}
10^{-1}
10^{0}

Summary

- Progress towards per datum uncertainty characterization of RO retrieval products.
- Dominant error sources have been taken into account.
- Systematic iono error can be better estimated (currently only an upper bound).
- Lower troposphere error characterization needs additional work (modeling tracking error & noise propagation thru nonlinear retrieval).
- Uncertainty estimates need to be verified.
- Retrieval errors from non-spherical atmosphere were not considered here (but were in Kursinski et al. 1997); they can be interpreted as *representation errors*.